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Investigation of Occupant Restraint Improvements to the SIIIS-3 Ejection Seat

Steven M. Pint
Chris E. Perry

January 1999

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Human Effectiveness Directorate
Biodynamics and Protection Division
Biodynamics and Acceleration Branch
BLDG 824 RM 206 2800 Q Street
Wright-Patterson AFB OH 45433-7947

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

Roger L. Stork

ROGER L. STORK, Colonel, USAF, BSC
Chief Biodynamics and Protection Division
Human Effectiveness Directorate
Air Force Research Laboratory

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Pint, Steven M. and Perry, Chris E.

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During the Front Line Ejection Equipment Tests (FLEET) program, higher than anticipated radical values were recorded using the 103 lb Lightest Occupant In Service (LOIS) manikin ejecting in the SIIIS-3 ejection seat with and F-15 forebody. The radical value is calculated using the seat acceleration in the x and y axes, and the Dynamic Response (DR) in the z axis. It was observed that the LOIS manikin was poorly restrained in the seat regardless of the tension applied to the harness straps. Three concepts have been identified that can be readily incorporated into the seat to improve occupant restraint. These concepts are: an improved seat cushion using a conforming material , inertia reel rollers that are fixed with respect to the headbox, and inflatable elements attached to the lap-belt as pace fillers. Tests with manikins were performed to evaluate the proposed improvements. The large ADAM (218 lb) manikin and the LOIS manikin were subjected to impacts along the +z, -x and +y axes using the AFRL Vertical Deceleration Tower (VDT) and Horizontal Impulse Accelerator (HIA). Test were conducted with the original seat configuration and with the proposed improvements incorporated into the seat. Manikin response characteristics were measured and results were compared to determine the improvements provided by the modifications to the SIIIS ejection seat.

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PREFACE

This experimental effort was conducted to measure the improvement in occupant restraint due to modifications made to the SIIIS-3 ejection seat. Three concepts were incorporated into the seat by the manufacturer and evaluated with manikins on the Vertical Deceleration Tower (VDT) and Horizontal Impulse Accelerator (HIA). The impact tests and data analysis described in this report were accomplished by the Biodynamics and Acceleration Branch, Biodynamics and Protection Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/HEPA) at Wright-Patterson Air Force Base OH. The tests were conducted under Cooperative Research and Development Agreement (CRDA) 98-106-HE-01. The collaborator for this CRDA was Universal Propulsion Company, Inc., Phoenix, AZ. Universal Propulsion Company, Inc. supplied all test articles and provided technical support for modification installation. Test facility and engineering support at AFRL/HEPA was provided by DynCorp, Inc., under contract F33601-96-DJ001.

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TABLE OF CONTENTS

PAGE NO.

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In FY 1996 and FY 1997, Congress appropriated funds in response to concerns that inadequate emphasis was being placed on aircrew protection for lightweight crewmembers and for ejections at higher air speeds. The House National Security Committee directed the Air Force and Navy to conduct tests on existing Navy, Marine Corps, and Air Force front-line trainer and tactical aircraft ejection seats for the purpose of verifying their predicted performance, and identifying problems and required corrective action. The Crew Escape Technologies (CREST) program of the Air Force Research Laboratory's Human Effectiveness Directorate conducted a series of ejection seat tests using lightweight manikins and current ejection seats (the ACES II, T-38 and SIIIS ejection seats) to accomplish this task. The test program was named Front Line Ejection Equipment Tests (FLEET). Data from these tests indicated a trend, consistent with predictions, that acceleration injury risk is higher with lightweight occupants in existing Air Force and Navy ejection seats, particularly at higher air speeds. Tests also indicated aircrew torso restraint systems and personnel equipment do not provide the full range of adjustment needed to accommodate lightweight, small stature crewmembers.

The SIIIS-3 seat is presently used by the U.S. Marine Corps' AV-8B and TAV-8B aircraft which are capable of vertical takeoff and landing. Approximately 225 SIIIS-3 ejection seats are currently in Navy and Marine Corps aircraft. The SIIIS-3 seat was designed and qualified to accommodate an occupant ranging from 135 to 212 pounds and has been a capable seat throughout the low-speed mode of operation. As a result of the Congressionally directed test program, Universal Propulsion Company (UPCo), the manufacturer of the SIIIS-3 seat, made several modifications to the seat to improve its ability to restrain the lightweight crewmember and reduce the acceleration injury risk. A Cooperative Research and Development Agreement (CRDA) was initiated between Air Force Research Laboratory (AFRL) and UPCo to investigate the effectiveness of the modifications. This report describes the results of the tests conducted by the Air Force to evaluate the improvements of the SIIIS-3 ejection seat.

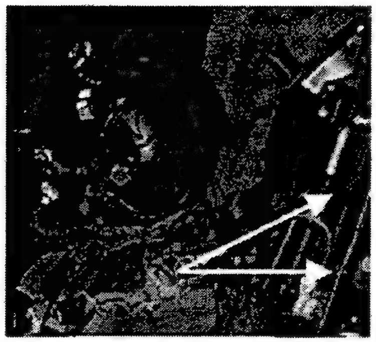
BACKGROUND

Improving occupant restraint in ejection seats has become more important in recent years due to the increasing performance of combat aircraft. High-speed ejections are considerably more dangerous to aircrew than those at lower speeds [4]. These higher speed ejections are cause for

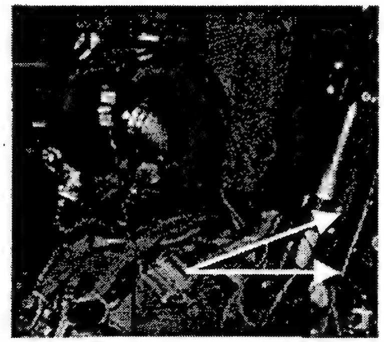
concern to the ejection seat designer because aerodynamic forces on the occupant and limb flail increase as airspeed increases [4,9]. Increased aerodynamic forces can cause excessive displacement of the occupant's torso, especially if the occupant is loosely restrained or poorly fitted within the restraint harness [5]. The expanded aircrew population, in particular those in the smaller anthropometric ranges (5th percentile and below), could be at increased risk for injury during ejection due to poor torso restraint.

One of the measures of injury potential for an ejecting crew member is the radical value. The radical value is calculated using the seat acceleration in the x and y axes, and the calculated Dynamic Response (DR) in the z axis [11]. During ejection tests, higher than acceptable radical values were recorded using the 103 lb Lightest Occupant In Service (LOIS) manikin ejecting in the SIIIS-3 ejection seat with an F-15 forebody. UPCo personnel also observed that the LOIS manikin was poorly restrained in the seat regardless of the tension applied to the harness straps.

The modifications to the SIIIS-3 ejection seat were designed to improve torso restraint and increase the seat's performance during high-speed ejections for the full aircrew population. Three concepts were identified and incorporated into the seat: a fixed inertia reel roller, a contoured seat cushion, and inflatable lap-belt spacers. The first modification is a fixed inertia reel roller. Currently, each inertia reel roller moves up and down with the seat bucket when adjusting for the various sitting heights of the occupants. With this arrangement, larger occupants are provided with good upper torso restraint. However, smaller occupant restraint is degraded since the inertia reel roller attachment point is located above the riser fitting and the inertia reel and riser straps are oriented approximately 30° above horizontal. The inertia reel and riser straps are nearly horizontal for larger occupants. Negative strap angles, with respect to the riser fittings, must also be avoided to eliminate compressive spinal loads during haulback [1]. Figure 1 shows a comparison of the original and modified inertia reel roller positions adjusted for a small occupant. The modification fixes the inertia reel rollers with respect to the headbox (seat pan will move with respect to the rollers), allowing the parachute riser straps to provide improved upper-body restraint as the seat is raised for small occupants. The riser strap angle in the original configuration is approximately 30°. With the modification, the angle were reduced to approximately 15-20°. The angle could be reduced even further if the seat was raised to its maximum upward travel limit. For our testing, the line of sight of the manikin was kept as consistent as possible for the large and small manikins. There was approximately 70 mm of upward travel left in the seat, but raising the seat any higher would have changed the line of sight.



Original Seat
28°



Modified Seat
15°

Figure 1. Comparison of Riser Angle

The second modification is a contoured seat cushion. The existing SIIIS-3 seat cushion is relatively flat and very firm. While research has shown this type of cushion has good performance for limiting spinal injuries during ejection [6,10], it has shortcomings in the areas of comfort and restraint. Different, conformal materials were used in the proposed cushion. The cushion was manufactured for UPCo by Oregon Aero, Inc. Conformal cushion materials, depending on their density, have adequate ejection performance while increasing comfort [2,3,6,7,10]. The extended side and rear panels in the proposed cushion were designed to assist in restraining the occupant during lateral accelerations. An adjustable conformal lumbar support cushion was also added to the seat back. Figure 2 shows a comparison of the original and proposed seat cushion.

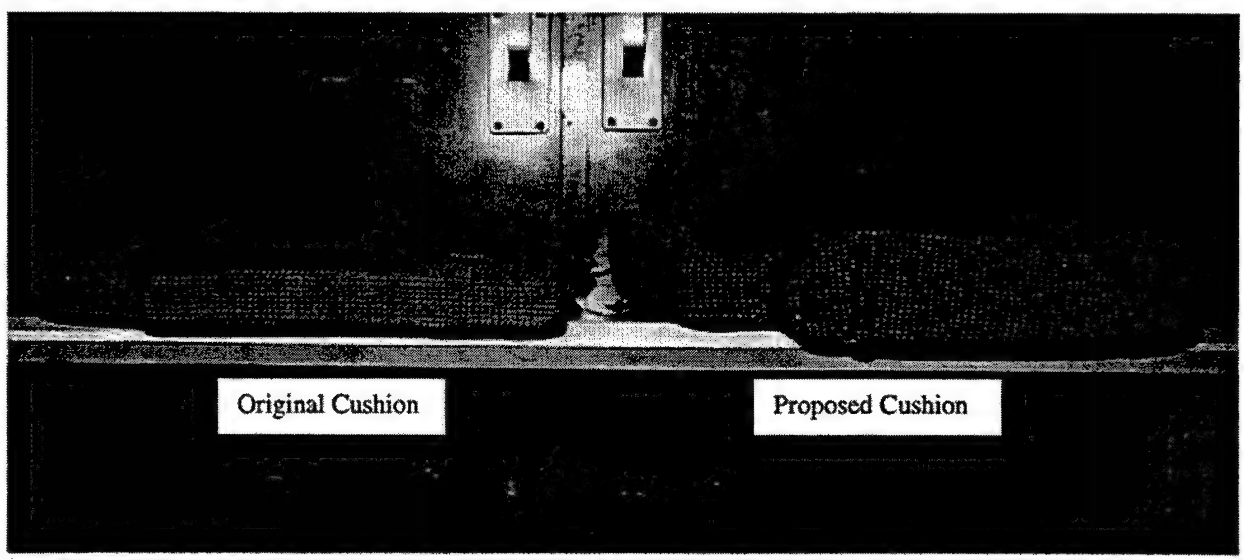


Figure 2. Seat Cushion Comparison

The final modification is a lap-belt inflatable. The physical dimensions of the SIIIS-3 seat preclude a fixed lap belt from providing equal restraint for both large and small occupant. The fixed spacing of the belt attachment points leaves excess "dead space" between the hips and the belt attachment points in small occupants. Based on the results and observations from the FLEET program, UPCo designed a pair of lap-belt-installed inflatables that act as space fillers and belt tensioners. The inflatables are attached to the underside of the lap belts, on each side near the occupant's hips. Figure 3 shows a headbox view of the prototype inflatables attached to the lap belt. Operationally, the inflatable would be filled at the time of ejection. For this study, it was pre-inflated. Design specifications for each of the modifications may be obtained from UPCo.

Figure 3. Lap-Belt Inflatable (Headbox View of Seat Pan)

METHODS

A series of impact tests were conducted with manikins in each of the orthogonal axes (-x – frontal, +y – lateral, and +z – vertical). The coordinate system follows the right-hand rule. The Horizontal Impulse Accelerator (HIA) was used for all –x and +y axis tests. Figure 4 shows the HIA setup for a +y axis test.

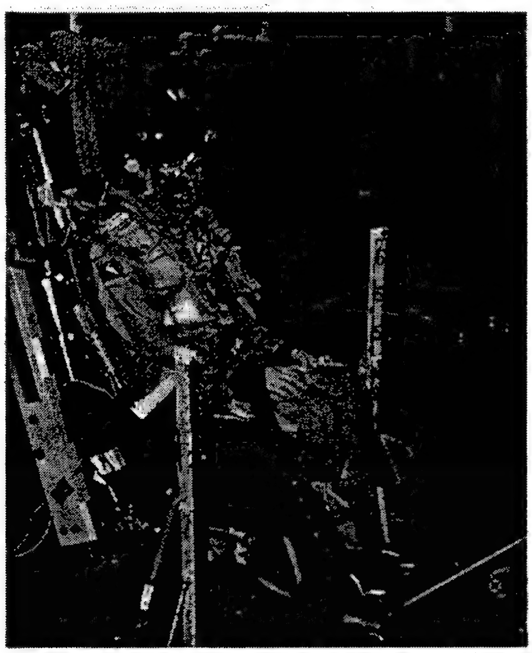


Figure 4. +Y Axis Test Configuration

The HIA is a hydraulically controlled, gas-energized piston that operates on the principle of differential pressures. The piston propels a test sled carrying the seat apparatus down a track. The shape and duration of the impact pulse are controlled by varying the hydraulic control volumes and gas pressures prior to each test.

The Vertical Deceleration Tower (VDT) was used for all +z axis tests. Figure 5 shows the VDT setup for a +z axis impact. The VDT facility consists of two vertical rails and a drop carriage. The carriage is allowed to enter a free-fall state (guided by the rails) from a pre-determined drop height. A plunger mounted on the rear of the carriage is guided into a floor-mounted cylinder filled with water and located between the vertical rails. A +Gz pulse (actually a deceleration pulse) is produced when water is displaced from the cylinder by the carriage-mounted plunger. The onset rate and duration of the deceleration pulse are controlled by varying the drop height of the carriage and changing the shape of plunger.

The test article for each test was the SIIIS-3 ejection seat. Both the large Advanced Dynamic Anthropomorphic Manikin (ADAM-L) (218 lb) and the LOIS (103 lb) manikin were tested in

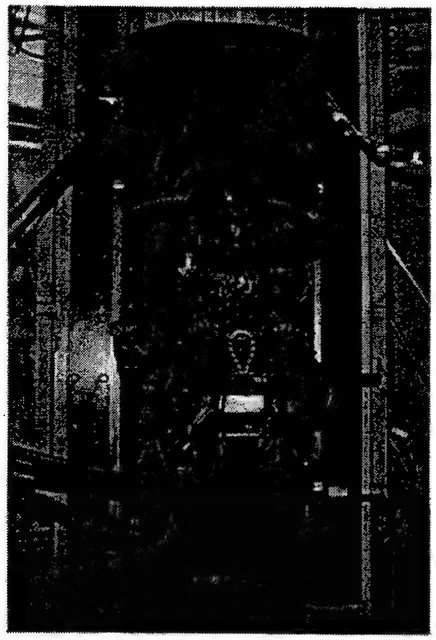


Figure 5. +Z Axis Test Configuration

each axis. The seat was tested in its operational configuration with the exception of the pyrotechnics and survival kit which were removed prior to testing. The vertical seat height adjustment was placed in the "full down" position for all ADAM-L tests to approximate the correct line-of-sight seat position in an aircraft. The manikin line-of-sight position was measured and marked for placement. The seat was positioned for the LOIS tests such that the line-of-sight position was approximately the same as for the ADAM-L manikin. The inertia reel was placed in the "manual lock" mode prior to each test to simulate the crewmember's position just prior to ejection. The shoulder and lap belts were pre-tensioned to 20 +/- 10 lbs prior to each test. Pre-loads were determined by using load-measuring fittings. The limbs were restrained to resemble the test conditions during the FLEET program. The manikin's legs were restrained by the SIIIS-3 leg restraints and the arms were restrained to the upper thighs using Velcro straps. The flight equipment was U.S. Navy issued and is listed in Table 1. The LPU-23 life preserver was not used during the +y axis ADAM-L tests in the original seat. In all other tests, the manikins wore the life support equipment listed in Table 1. The impact pulse for each cell was chosen to approximate the accelerations observed during the FLEET program.

Table 1. Life Support Equipment

LOIS Manikin (103 lb)	ADAM-L Manikin (218 lb)
HGU-85/P Helmet, Medium	HGU-85/P Helmet, X-Large
MBU-12/P Mask, Series Short	MBU-12/P Mask, Series X-Long
LPU-23/P Life Preserver	LPU-23/P Life Preserver
PCU-56/P Harness, Small	PCU-56/P Harness, Large
CSU-13B/P G-Suit, Small-Regular	CSU-13B/P G-Suit, Large-Long
CSU-27/P Flight Coverall, 34 Short	CWU-27/P Flight Coverall, 46 Long
Flyer's Boots, 7	Flyer's Boots, 12 Wide

It was not possible to duplicate the dynamics of a full-scale ejection test, but for the purposes of this evaluation the chosen parameters were sufficient to make a comparison in the manikin responses using the original and modified seat. The original seat was tested first in each axis. Following cell F (see Table 2), UPCo personnel installed the modified inertia reel rollers, seat cushions, and lap-belt inflatables. After the seat was modified, an identical series of impact tests was conducted in each axis. Three tests were conducted in each cell. The test conditions are shown in Table 2.

Table 2. Test Matrix

FACILITY	CELL	SEAT CONFIG.	MANIKIN	RISE TIME (sec)	PULSE DURATION (sec)	PEAK ACCEL. (G)	IMPACT AXIS
HIA	M	Original	218 lb	.150	.300	6	+Y
HIA	N	Original	103 lb	.150	.300	6	+Y
HIA	O	Original	218 lb	.100	.200	10	-X
HIA	P	Original	103 lb	.100	.200	10	-X
VDT	E	Original	103 lb	.060	.180	15	+Z
VDT	F	Original	218 lb	.060	.180	15	+Z
VDT	G	Modified	103 lb	.060	.180	15	+Z
VDT	H	Modified	218 lb	.060	.180	15	+Z
HIA	I	Modified	103 lb	.150	.300	6	+Y
HIA	J	Modified	218 lb	.150	.300	6	+Y
HIA	K	Modified	103 lb	.100	.200	10	-X
HIA	L	Modified	218 lb	.100	.200	10	-X

The test sled contained instrumentation to measure the sled acceleration and velocity. Each manikin was instrumented to collect biodynamic response data including neck loads and moments, head and chest accelerations, and lumbar loads and moments. Data were collected

using two different data acquisition systems, a Pacific Instruments and an EME on the VDT and HIA, respectively. Manikin position and displacement data were collected using the SELSPOT Data Collection System with target locations at the top of head, side of head, mask, shoulder, chest, and hip/upper thigh. High-speed video coverage was provided by an on-board Kodak video system operating at 500 frames/second.

RESULTS

A total of 39 channels of manikin response data were collected for each test. Displacement data for each target were also collected. For each axis tested, several channels were identified as critical because they provided information most relevant to assessing seat performance. A case could be made for analyzing each channel measured, but it was decided to analyze only the channels most useful for the purposes of evaluating the torso responses of the manikin before and after the seat modifications were made. These channels are shown in the data summary for both the original and modified seat in Tables 3 through 8. A measure of the compared manikin response is shown in the right-hand column of each table. In each case, where a down arrow (↓) is shown, the manikin response was reduced (improved) in the modified seat. Conversely, where an up arrow (↑) is present, the manikin response was amplified (degraded) in the modified seat. The value is quantified as a percentage of the original seat response.

In the x axis, the response of the LOIS manikin was improved for most responses after the seat modifications were implemented (see Table 3). The lap-belt loads, however, increased significantly. This could be explained by the modifications to the seat that eliminated previously existing load paths during impact. In the original configuration, the parachute risers carried most of the upper torso load. With the modifications, the lap belt and parachute risers had more comparable loads. The measured displacements of selected LED targets located in the torso area also decreased with the modifications in place. Analysis of the high-speed video confirmed reduced displacement of the manikin torso. The ADAM-L manikin data for the x axis were less conclusive (see Table 6). A reduction in the lumbar loads was observed; however, the parachute riser and lap-belt loads increased and the remaining data channels of interest showed little response differences between the original and modified seat. Video analysis of the ADAM-L in the x axis was inconclusive.

The y axis data were somewhat inconclusive. The LOIS showed decreased parachute riser and lap-belt loads, and chest displacements were reduced with the modified seat (see Table 4). The lumbar loads were reduced slightly but other parameters of interest did not vary significantly. Video analysis confirmed reduced head, chest and overall upper torso displacements. The ADAM-L response also varied in the y axis. Angular chest accelerations and lumbar forces and moments were reduced; however, both shoulder and upper thigh displacements were increased. Other channels of interest did not vary significantly (see Table 7). Video analysis of the ADAM-L manikin in the y axis was inconclusive.

The LOIS data for the z axis showed that the modifications to the seat degraded the manikin response in nearly all categories of interest. This is most likely due to the cushion material characteristics. The modified cushion is softer than the original, and the displacement data and video analysis show that the manikin tended to sink further into the cushion during impact. The softer cushion may be responsible for the increased loads and moments obtained from the LOIS in the z axis (see Table 5). The ADAM-L data were mixed in the z axis. Since the ADAM-L is approximately 115 lbs heavier than the LOIS, it is possible that it "bottoms out," or significantly compresses the proposed cushion prior to impact. This could explain the reduced chest displacement. Other channels of interest gave a mixed response and are therefore inconclusive (see Table 8). Video analysis was inconclusive for the ADAM-L in the z axis.

Table 3. LOIS Manikin, X Axis

Data Channel	Original Seat	Modified Seat	% Difference
Chest X Acceleration (G)	13.75	13.629	↓ 0.8
Lumbar X Force (lb)	33.306	27.41	↓ 17.7
Lumbar Y Moment (in-lb)	353.963	290.714	↓ 17.9
Parachute Riser Load (lb)	639.097	587.691	↓ 8.0
Lap-Belt Load (lb)	177.85	330.966	↑ 46.3
Neck X Force (lb)	165.537	161.480	↓ 2.5
Shoulder Displacement (in)	3.791	3.216	↓ 15.2
Chest Displacement (in)	3.578	3.243	↓ 9.4
Hip/Upper Thigh Disp. (in)	2.378	1.820	↓ 23.5

Table 4. LOIS Manikin, Y Axis

Data Channel	Original Seat	Modified Seat	% Difference
Chest Y Acceleration (G)	9.00	9.71	↑ 7.3
Chest Angular Accel. (Rad/s^2)	120.056	123.9	↑ 3.1
Lumbar Y Force (lb)	129.687	112.680	↓ 13.4
Parachute Riser Load (lb)	341.952	260.550	↓ 23.8
Lap-Belt Load (lb)	332.425	165.937	↓ 50.1
Neck Y Force (lb)	102.484	106.79	↑ 4.0
Shoulder Displacement (in)	6.930	6.903	↓ 0.4
Chest Displacement (in)	7.863	5.848	↓ 25.6
Hip/Upper Thigh Disp. (in)	5.313	5.449	↑ 2.5

Table 5. LOIS Manikin, Z Axis

Data Channel	Original Seat	Modified Seat	% Difference
Chest Z Acceleration (G)	19.346	21.399	↑ 9.6
Chest Angular Accel. (Rad/s^2)	109.97	131.548	↑ 16.4
Lumbar Z Force (lb)	625.986	725.746	↑ 13.7
Lumbar Y Moment (in-lb)	371.11	402.434	↑ 7.8
Parachute Riser Load (lb)	88.103	76.528	↓ 13.1
Lap-Belt Load (lb)	42.77	54.381	↑ 21.4
Neck Z Force (lb)	215.873	253.058	↑ 14.7
Shoulder Displacement (in)	1.148	1.879	↑ 38.9
Chest Displacement (in)	1.377	2.147	↑ 35.9
Hip/Upper Thigh Disp. (in)	1.034	1.110	↑ 6.8

Table 6. ADAM-L Manikin, X Axis

Data Channel	Original Seat	Modified Seat	% Difference
Chest X Acceleration (G)	14.149	14.15	-
Lumbar X Force (lb)	139.537	131.6	↓5.7
Lumbar Y Moment (in-lb)	413.921	422.5	↑2.0
Parachute Riser Load (lb)	838.754	1019.967	↑17.8
Lap-Belt Load (lb)	817.448	932.24	↑12.3
Neck X Force (lb)	188.635	193.047	↑2.3
Shoulder Displacement (in)	5.746	5.563	↓3.2
Chest Displacement (in)	4.651	4.983	↑6.7
Hip/Upper Thigh Disp. (in)	4.203	3.894	↓7.4

Table 7. ADAM-L Manikin, Y Axis

Data Channel	Original Seat	Modified Seat	% Difference
Chest Y Acceleration (G)	11.748	11.943	↑1.6
Chest Angular Accel. (Rad/s^2)	149.880	94.147	↓37.2
Lumbar Y Force (lb)	222.907	164.513	↓26.2
Lumbar X Moment (in-lb)	1950.45	1387.86	↓28.8
Parachute Riser Load (lb)	597.466	440.013	↓26.4
Lap-Belt Load (lb)	567.737	617.89	↑8.1
Neck Y Force (lb)	146.115	156.593	↑6.7
Shoulder Displacement (in)	8.913	10.216	↑12.8
Chest Displacement (in)	10.159	9.183	↓9.6
Hip/Upper Thigh Disp. (in)	6.844	8.327	↑17.8

Table 8. ADAM-L Manikin, Z Axis

Data Channel	Original Seat	Modified Seat	% Difference
Chest Z Acceleration (G)	24.172	23.727	↓1.8
Chest Angular Accel. (Rad/s^2)	187.130	143.856	↓23.1
Lumbar Z Force (lb)	2044.935	2009.927	↓1.7
Lumbar Y Moment (in-lb)	1043.648	1375.897	↑31.8
Parachute Riser Load (lb)	69.950	100.13	↑30.1
Lap-Belt Load (lb)	52.386	41.68	↓20.4
Neck Z Force (lb)	262.405	236.533	↓9.9
Shoulder Displacement (in)	2.327	2.481	↑6.2
Chest Displacement (in)	3.632	2.356	↓35.1
Hip/Upper Thigh Disp. (in)	1.679	1.755	↑4.3

DISCUSSION

Overall, the results of this study were inconclusive. While selected improvements in manikin response were shown, they were not observed consistently for each axis. This may be attributed to the emphasis on the lateral (y axis) impact case during the design of the modifications. Items of particular interest were the improved overall performance of the LOIS manikin in the x axis and the reduced upper torso displacement of the LOIS manikin in the y axis with the modifications installed. In addition, the ADAM-L showed reduced torso loads and accelerations in the y axis with the modifications. To the contrary, the LOIS response in the z axis was degraded noticeably by the modifications and several of the other LOIS conditions were inconclusive. The ADAM-L responses, with the exception of those noted above, were largely inconclusive.

CONCLUSION

The goal of this study was to determine the effect of the proposed SIIIS-3 ejection seat modifications on manikin response to impact in a simulated high-speed ejection environment. It is important to note that this study was not meant to baseline the performance of the modifications or the ejection seat. A full-scale ejection test program or a human subject study is better suited for goals of that nature. It is also difficult to extrapolate the results obtained in the laboratory to those observed during an ejection. Combined aerodynamic forces, moment of inertia effects, and seat stability characteristics cannot be simulated in a laboratory environment.

The results reported here are meant to provide insight into technologies that may help achieve full accommodation and restraint improvements in existing military ejection systems. A limited data sample was obtained during this study (three (3) tests per cell). This does not allow a statistically significant evaluation of the data. However, there was minimal variation of the data within cells, suggesting that the tests were well controlled and repeatable. In addition, the modifications to the seat were tested as a whole system. Therefore the individual contribution of each modification to the manikin response is unknown.

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